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UTILIZATION OF AGRO-ECOLOGICAL ZONES DATABASE
AND
INSTALLATION OF GIS FOR AGRICULTURAL DEVELOPMENT
BGD/95/006

GIS-

TECHNICAL NOTE
ON
ESTIMATION OF DROUGHT SEVERITY
USING GIS

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ESTIMATION OF DROUGHT SEVERITY USING GIS

1. Introduction

Since the previous estimation of drought severity by Bangladesh Agricultural Research Council (BARC), which was published in 1990 in the title of "Drought in Bangladesh Agriculture and Irrigation Schedule for Major Crops" , there has been no attempts in updating the national drought maps. Since the initiation of the GIS Project, the climatic database such as rainfall, Evapotranspiration humidity, temperature, sunshine and cloud cover data collected from the respective organizations and thereby updated the previous climatic database, which was stored in the form of climatic resources inventory as part of the National Land Resources Inventory (LRI).. Under GIS project, attempt has been taken on updating of the previous drought maps incorporating latest climatic database and other dominant factors e.g. soil moisture-holding capacity, soil percolation rate. The mapping unit in the previous study was considered as soil association polygons accompaning the necessary attributes with overlaying climatic factors e.g P-Pre-kharif Transition period, K-Kharif and Rabi growing period, T-Cool temperature lines and e-extreme summer temperatures on to it. In the current GIS project, since all the soil and land resources database and also climatic database have successfully been transformed into GIS system and updated as of the present state of data availability, this was the right time to update the drought maps analyzing latest climatic database and incorporating more layers under GIS platform.

2. Objectives

The objective of this research is to find out areas prone to drought in different seasons of the year. Drought prone areas mainly located in the western part of the Bangladesh as estimated in the previous study. Drought is generally considered for the agricultural crops in three different seasons khraif-II, Rabi and Pre-kharif. In the Kharif-II (July-Octber), T.Aman is considered to be the major crops grown and is affected due to shortage of available soil moisture. Since T.Aman is grown in the wet season, soils having higher moisture holding capacity and low percolation rate with high to medium highland is mostly suitable for T.Aman and those are normally not affected by drought. In the pre-kharif season (March-June) Aus crops (Jute or Aus paddy) is affected. In Rabi season (Nov-Feb) Rabi crops (Wheat/Potato etc) are normally affected due to shortage of available moisture in the soil. In the Rabi season, normally the whole period is non-rainfall situation, only the residual soil moisture supports growing crops in this season. In the rabi season crops are grown in such areas, where moisture-holding capacity in the soil is higher and supplementary irrigation is ensured.

Considering the above factors, GIS is selected to be used as a tool to analyze all the above mentioned factors and thereby delineate drought severity maps as follows:

a) Kharif (T.Aman) drought prone area map;
b) Rabi drought prone area map; and
c) Pre-Kharif drought prone area map.

3. Scenarios Considered

- Soil Characteristics that are mainly from the LRI database which is a survey results that reflects average condition in the soil.
- Climatic Characteristics (LGP-Length of Growing period) that was calculated based on the time series database and calculated an arithmetic average that has 50% probability i.e average situation
- Rainfall Uncertainty (rainfall availability at 80% probability), which represent ensured rainfall situation i.e. this rainfall situation, is quite likely to occur almost every year.

Based on the above scenarios discussed for different factors the drought severity is calculated and weight is given and accumulated in such a way that it represents an average situation that has the probability of occurrences is 50% i.e. it might occur once in two or two and half years.

4. Factors considered

In the current activity similar methodology followed on analyzing the factors as it was followed in the previous study in undertaking the tasks. The potentialities of using GIS in this task is that one can consider as many factors as one desires, analyze them and this tools helps to delineate drought prone areas.

In determining the potential factors experts from the project (BARC's core staffs and consultants) and national experts available in the country were consulted. As it is known that drought is a combined effect of climate and soil properties (specially factors those determines the moisture availability in soil). Therefore mainly the soil and climatic factors were considered in delineating drought prone areas.

4.1 Kharif Drought area mapping

Following factors have been considered in estimating the kharif-II drought severity areas:

Table 1 : Kharif (T.Aman) drought factors

Soil Factors	1	Available moisture holding capacity
	2	Soil percolation rate
Climatic Factor	3	Kharif Length of growing period (days)-K Values
Moisture Availability due to Rainfall uncertainty	4	Percentage of dry sub-humid (P<0.5PET) decades
	5	Percentage dry decades (decades of no rainfall)

4.2 Rabi Drought area mapping

Following factors have been considered in estimating the intensity of rabi drought severity areas:

Table 2 : Rabi drought factors

Soil Factors	1	Available moisture holding capacity
Climatic Factor	2	Rabi Length Length of growing period (days)-R values
Moisture Availability due to Rainfall uncertainty	3	Percentage of dry sub-humid (P<0.5PET) decades
	4	Percentage dry decades (decades of no rainfall)
External Water Supply	5	Ensured Irrigation

3.3 Pre-Kharif Drought area mapping

Following factors have been considered in estimating the pre-kharif drought severity areas:

Table 3 : Pre-Kharif drought factors

Soil Factors	1	Available moisture holding capacity
Climatic Factor	2	Pre-Kharif Transition period (days)-P values
	3	Total Length of Growing Period (days)-LGP
Moisture Availability due to Rainfall uncertainty	4	Percentage of dry sub-humid (P<0.5PET) decades
	5	Percentage dry decades (decades of no rainfall)

To consider the pre-kharif uncertainty of rainfall, the pre-kharif transition period (P) (numbers of uncertain days required to start full monsoon after the dry rabi period) is normally taken into account. Total LGP is considered here, because the Total LGP determines the available atmospheric water that is potentially available for crops to be grown for the whole growing seasons.

5 Estimate different parameters

5.1 Soil Parameter: Available Moisture Holding Capacity (AMHC)

Using LRI summery program developed at the GIS project, countrywide available moisture holding capacity theme was produced. Five classes of moisture holding capacity defined in the LRI as follows:

Moisture Classes	Moisture Availability range
1	<100 mm
2	100-200 mm
3	200-300 mm
4	300-400 mm
5	> 400 mm

The LRI database has one to many relationships from its mapping units with its soil attribute database due to fact that one soil association contains different percentage of occurrence of soil series. Therefore, for summarizing the attribute data to assgin a legend class to the map units, following category of dominance were defined such as a class occurring >80% is predominant class, a class occurring 60-80% is the mostly class, a class occurring >30% is with some class, a class occurring >15% is the mixed classes and a class occurring < 10% is insignificance. Drought weights (1-5) signifying occurrence of different intensity of drought were also assigned, where 1-very prone to drought i.e. low moisture holding capacity to 5-very low prone to drought i.e. high moisture holding capacity.

The classes are obtained after summarizing is listed in Table 4. The corresponding weight to the classes that is assigned is also listed. An alternative way of assigning weight to different classes has been devised and applied also in this study.

5.1.1 Revised mapping of the AMHC factor

An alternate way of assigning drought severity weight to different classes is devised based on the percentage of occurrence of different classes within each soil associations. The detailed table found after summarization (SUM2 Table) used as input and opened in excel. Five moisture classes were assigned to different drought severity weight as shown in Table 5. The procedure of mapping is explained in details in the six monthly reports of the National GIS consultant for June-December '2000.

A cumulative weight was calculated under excel by multiplying percentage of occurrence of a class with its corresponding weight (Table 5). A part of the total worksheet is shown in Table 6 and brief description of the fields and calcuiation procedure is given at the bottom of the table. Weight assigned based on both the procedure is also compared in the Table. This procedure of applying weight is robust, logical and automated which can be used for other factors as well as for mapping of any theme of the LRI database. Finally using the MHCWT_New field the moisture holding capacity map is produced as shown in Figure 1. This theme was used as one of the input for drought severity estimation/drought mapping.

Table 4 : Moisture Classes for mapping based on the LRI database

CLASS	WT	CLASS	WT
Predominantly class 5	5	Mixed 5 2	3
Predominantly class 4	4	Mixed 4 3 2	4
Predominantly class 3	3	Mixed 4 3 1	4
Predominantly class 2	2	Mixed 4 3	4
Predominantly class 1	1	Mixed 4 2 3	3
Mostly class 5	5	Mixed 4 2	3
Mostly class 4	4	Mixed 3 5 4	4
Mostly class 3	3	Mixed 3 4 2	3
Mostly class 2	2	Mixed 3 4	3
Mostly class 1	1	Mixed 3 2 5	3
Mostly 5 with some 3	5	Mixed 3 2 4	3
Mostly 5 with some 2	5	Mixed 3 2 1	2
Mostly 4 with some 3	4	Mixed 3 2	3
Mostly 4 with some 2	4	Mixed 3 1 2	2
Mostly 4 with some 1	4	Mixed 2 5 3	3
Mostly 3 with some 5	3	Mixed 2 4 3	3
Mostly 3 with some 4	3	Mixed 2 4	3
Mostly 3 with some 2	3	Mixed 2 3 5	3
Mostly 3 with some 1	3	Mixed 2 3 4	3
Mostly 2 with some 5	2	Mixed 2 3 1	2
Mostly 2 with some 4	2	Mixed 2 3	2
Mostly 2 with some 3	2	Mixed 2 1 3	2
Mostly 2 with some 1	2	Mixed 2 1	2
Mostly 1 with some 4	1	Mixed 1 4 3	2
Mostly 1 with some 3	1	Mixed 1 3 2	2
Mostly 1 with some 2	1	Mixed 1 3	2
Mixed 5 3 2	4	Mixed 1 2 3	2
Mixed 5 3	4	Mixed 1 2	1

Table 5 : Assigned weight to the moisture classes

Moisture Classes	Moisture Availability range	Drought Weight	Drought Severity
1	<100 mm	1	Very severe
2	100-200 mm	2	Severe
3	200-300 mm	3	Moderate
4	300-400 mm	4	Low
5	> 400 mm	5	Very Low

Table 6: Alternative Moisture holding capacity weight calculation procedure

AEZCODE	IARE	SM1_P	SM2_P	SM3_P	SM4_P	SM5_P	CLASS	MHCWTPERC	MHCWT_OLD	MHCWT_NEW
AB658	12899	0	85	15	0	0	Predominantly class 2	43	2	2
AL220	10678	0	15	85	0	0	Predominantly class 3	57	3	3
AL221	11209	0	45	54	1	0	Mixed 3 2	51	3	3
AL222	17954	0	78	22	0	0	Mostly class 2	44	2	2
AL223	30037	0	89	11	0	0	Predominantly class 2	42	2	2
AL224	1388	0	100	0	0	0	Predominantly class 2	40	2	2
AL288	7009	0	100	0	0	0	Predominantly class 2	40	2	2
BA144	51261	0	37	53	10	0	Mixed 3 2 4	55	3	3
BA144U	14413	0	37	53	10	0	Mixed 3 2 4	55	3	3
BA145	765	0	2	0	98	0	Predominantly class 4	79	5	5
BA146	4148	0	1	5	94	0	Predominantly class 4	79	5	5
BA146U	15673	0	1	5	94	0	Predominantly class 4	79	5	5
BA262	21942	33	66	1	0	0	Mostly 2 with some 1	34	2	2
BA263	1054	14	45	41	0	0	Mixed 2 3 1	45	2	2
BA264	18998	40	30	30	0	0	Mixed 1 3 2	38	2	2
BA265	886	32	53	16	0	0	Mixed 2 1 3	37	2	2
BA289	34898	16	0	84	0	0	Predominantly class 3	54	3	3
BA317	34001	0	31	69	0	0	Mostly 3 with some 2	54	3	3
BA341	7228	0	51	44	5	0	Mixed 2 3	51	3	3
BA401	181	0	95	5	0	0	Predominantly class 2	41	2	2
BA402	6214	0	60	40	0	0	Mostly 2 with some 3	48	3	3
BA403	985	0	5	94	1	0	Predominantly class 3	59	3	3
BA627	15059	0	37	63	0	0	Mostly 3 with some 2	53	3	3
BA73	13729	0	54	41	5	0	Mixed 2 3	50	3	3
BA74	3967	0	28	6	67	0	Mostly class 4	68	4	4

Table Fields : **AEZCODE**-Soil Association Code, **Iarea**-Area in ha of the association.**SM1_P to SM5_P** : Percentage of occurrences of different soil moisture holding capacity classes, **Class** : The Mapping class defined by the AEZ-Summary program. **MHCWTPerc** : Moisture holding capacity weight cumulative percentage calculated as, Cumulative index = Sum of (SM1_P*1+SM2_P*2+SM3_P*3+SM4_P*4+SM5_P*5)/5. **MHCWT_Old**-Weight assigned as mentioned above (Table-4), **MHCWT_New**: New weight calculated based on the % threshold of the **MHCWTPerc** Value as 1: <33%, 2:33-45%, 3:46-60%, 4:61-75% & 5:>75%, where 1 to 5 represents the moisture classes

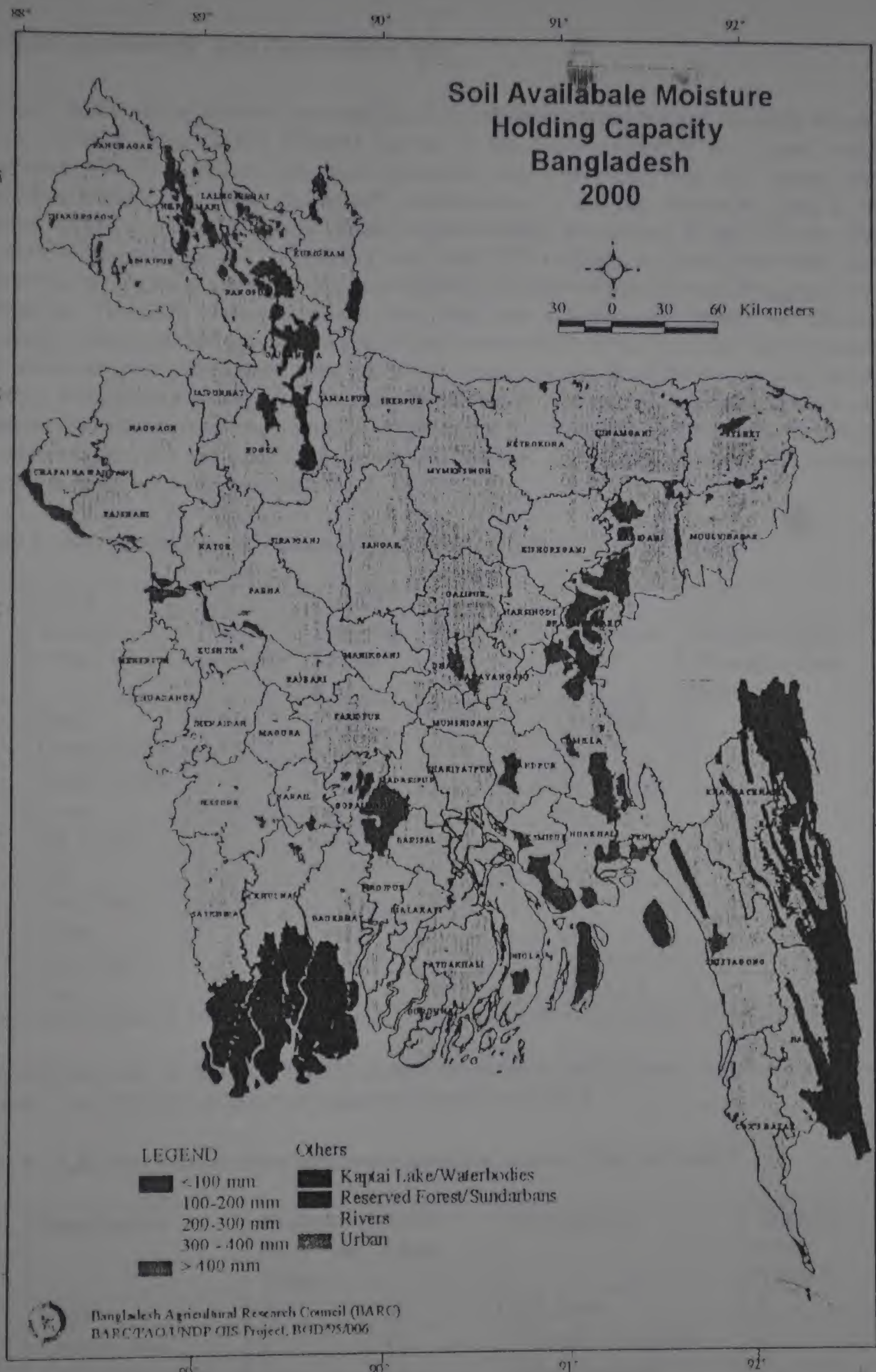

Figure 1: Soil Moisture Holding Capacity Classes

5.2 Soil Parameters: Soil Percolation rate

Soil percolation rate is another important factor to estimate drought because normally drought in the T.Aman crop period (Kharif) occurs in the high permeable soil (sand, sandy loam/sandy silt etc.) rather than low permeable soils (clay, silty clay etc), where other conditions remains the same. In the LRI, information on soil percolation is given as the heading of soil permeability; three classes of permeability are defined in the LRI e.g. slow (<12 cm /day), moderate (12-305 cm/day) and rapid (305 cm/day). It is understood that these classes are very lumped and too much generalized to use this information for drought severity estimation. Therefore through consultation with soil scientist and based on different literature, a more detailed percolation rate theme was worked out based on the topsoil texture. Five different percolation rate were identified based on the 9 different top soil texture property those were considered to be used in this study. The corresponding weights to soil permeability class were also assigned a weight factor for drought prone areas due to the soil percolation rate. The relationship between soil textures and soil percolation arte, drought severity weights are shown in Table 7.

Table 7 : Soil properties in relation with the soil texture class

	Col-1	Col-2	Col-3	Col-4	Col-5	Col-6
SL No	Texture Class	Field Capacity*	Wilting Point*	Available Capacity *	Percolation Rate**	Drought ratings** (Drought prone areas)
1	Sand	0.12	0.04	0.08	Very high	1
2	Loamy Sand	0.14	0.06	0.08	High	2
3	Sandy Loam	0.23	0.10	0.13	High	2
4	Loam	0.26	0.12	0.14	Medium	3
5	Silt Loam	0.30	0.15	0.15	Medium	3
6	Silt	0.32	0.15	0.17	Low	4
7	Silty Clay Loam	0.34	0.19	0.15	Low	4
8	Silty Clay	0.36	0.21	0.15	Very Low	5
9	Clay	0.36	0.21	0.15	Very Low	5

**Values obtained from ASCE, 1990, Table 2.6, p.2,* ** Values assigned in consultation with the soil scientist

In the LRI there are 20 different texture classes are defined and 9 classes of textures as shown in Table 7 are related to 20 textural classes as shown in Table 8.

Table 8 : LRI Soil texture class and corresponding texture class of Table 7

AEZ Class	Description	Texture class in Table 7	AEZ Class	Description	Texture class in Table 7
1	Sand	1	11	Silt loam	5
2	Loamy sand	2	12	Gravelly clay loam	7
3	Loamy fine sand	2	13	Silty clay loam	7
4	Sandy loam	3	14	Clay loam	7
5	Fine sandy loam	3	15	Silty clay	8

AEZ Class	Description	Texture class in Table 7	AEZ Class	Description	Texture class in Table 7
6	Very fine sandy loam	3	16	Clay	9
7	Gravelly sandy clay loam	3	17	Mucky clay	9
8	Sandy clay loam	3	18	Muck	9
9	Loam	4	19	Peaty Muck	9
10	Silt	6	20	Peat	9

Following steps were followed to create percolation rate map from the topsoil texture data of LRI.

- Use LRI Summary program, select TX-Topsoil texture as a classification field, and choose AEZ-soil association, as the mapping polygon and maps and tables are the output options.
- Use assign reclassification (regroup) option (e.g. Yes) and assign values as per Table 8
- Use default cutoff percentages
- In the editing class dialog box, choose "Continue" and at the end two tables NTX_AEZCODESUM2 and NTX_AEZCodeSUM3 tables will be displayed and a view named NTX_AEZCode_View will be displayed.
- Use NTX_AEZCodeSum2 Table and use the alternative procedure (explained in section 4.1 and Table 6).
- Reclassify the 9 texture classes with the 5-percolation rate classes as given in table 7, col-5.
- Finally the percolation map is obtained by assigning the percolation rate class applying the same procedure of weight application to different percentage of occurrence and thereby finally assigning the legend to the map unit as explained in Table 6.

The percolation rate map is shown in Figure 2. This percolation rate theme was used as one of the theme for analysis in delineating the drought prone areas.

For further documentation on the LRI Summary program and steps, please see six monthly report of the System Analyst/Programmer of July-December 2000.

In summary weight grids of the soil themes are calculated based on the weight of the soil available moisture holding capacity and soil percolation rate theme as shown in Table 9. These weight grids are used later on for computing the drought severity areas.

Table 9: Assignment of weight to different soil factors

Factor	Values of different factors				
Weight	1	2	3	4	5
Soil Moisture	<100 mm	100-200 mm	200-300 mm	300-400 mm	>400 mm
Soil Percolation rate	Very high	High	Moderate	Low	Very Low

Weights implies (1-Very High, 2-High, 3-Moderate, 4-Slight 5-None) prone to drought for the specific factor

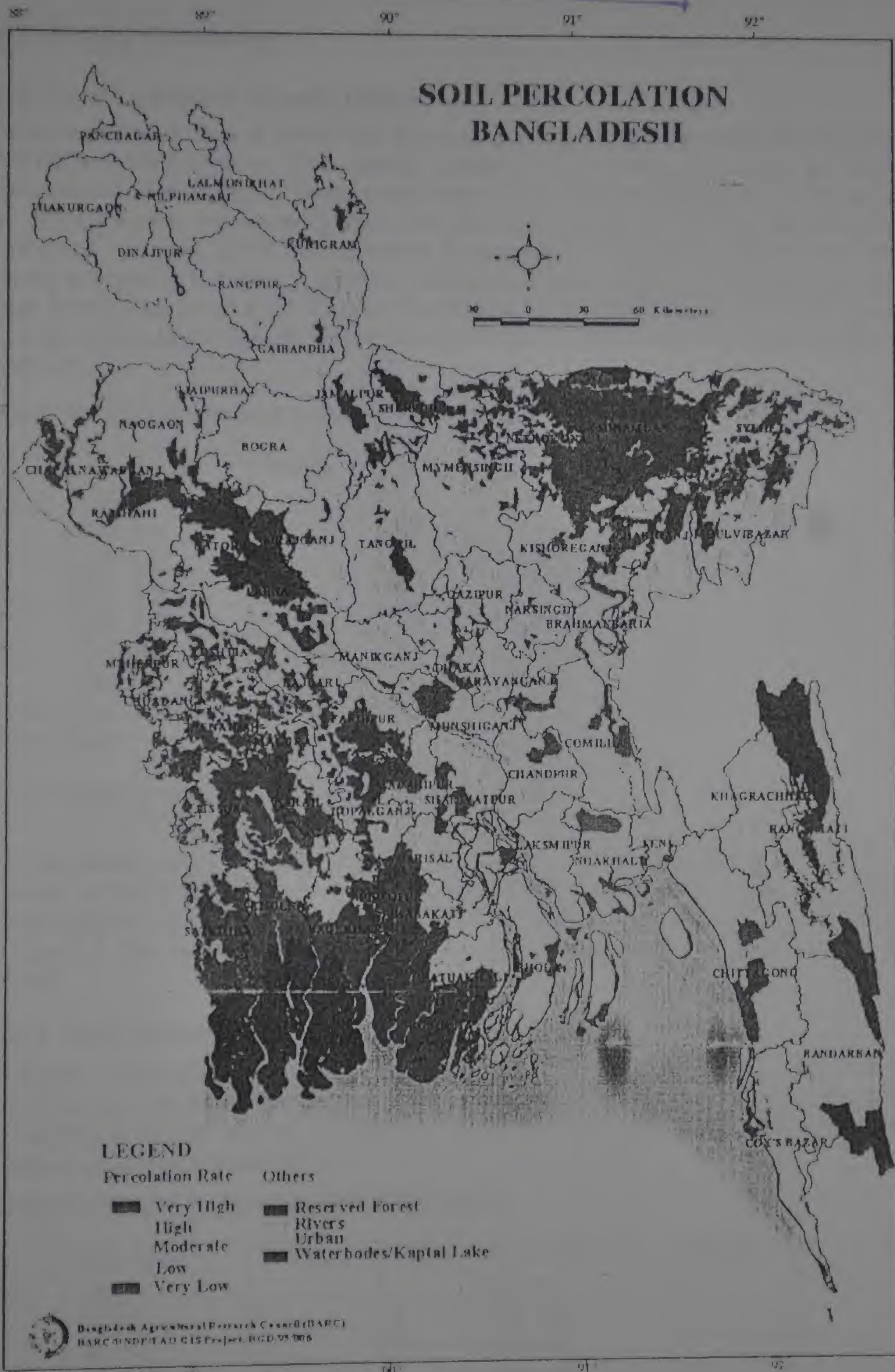

Figure 2 : Soil Percolation rate Map (Qualitative)

5.3 Climatic Parameters

5.3.1 Kharif Length of Growing Period

Analyzing climatic data of 1960-1990, kharif length of growing period was calculated for all BWDB and BMD stations (291 stations) using APT4.0 software (developed by FAO for calculation of Net Biomass, Evapo-transpiration, Crop Water requirement etc.). Climatic data in APT4.0 format was provided and using the CDA module of APT4.0 kharif LGP was calculated. Average kharif LGP is shown in Appendix-A. The average kharif LGP Map is shown in Figure 3. In Figure 3, there are 12 different classes of K-LGP zones (each having 15 days interval) are found from the data. Considering the fact that as higher the LGP lower the drought probability, a drought severity weight to the K-LGP values is assigned as shown in Table 10.

Table 10: Weight Assigned to Kharif LGP surface

SL No	Kharif LGP (Days)	Weight	Sl No	Kharif LGP (Days)	Weight
1	185-200	1	7	275-290	4
2	200-215	1	8	290-305	4
3	215-230	2	9	305-320	5
4	230-245	2	10	320-335	5
5	245-260	3	11	335-350	5
6	260-275	3	12	350-365	5

1-Very prone to drought, 2-Moderate drought, 3-Less Drought, 4-Slight
5-No drought.

5.3.2 Total Length of Growing Period (Rabi+Kharif)

As mentioned earlier that this factors was considered for estimating pre-kharif drought severity estimation. Based on historic climatic data analysis (1960-90) average total length of growing period (days) calculated using APT4.0 and the corresponding LGP surface is shown in Figure 4. This factor signifies the overall moisture situation that could be used in pre-kharf period.

5.3.3 Rabi LGP and corresponding weight to drought severity

In Figure 5, there are 5 different classes of Rabi-LGP zones (each having 10 days intervals) are found from the data. Considering the fact that as higher the Rabi LGP lowers the drought probability in the rabi season, therefore a drought severity weight to the Rabi LGP-values is assigned as shown in Table 11.

Table 11: Weight Assigned to Rabi LGP surface

SL No	Rabi LGP (Days)	Weight	Sl No	Rabi LGP (Days)	Weight
1	80-90	1	5	120-130	5
2	90-100	2	6	130-140	5
3	100-110	3	7	140-150	5
4	110-120	4			

1-Very prone to drought, 2-Moderate drought, 3-Less Drought, 4-Slight, 5-No drought

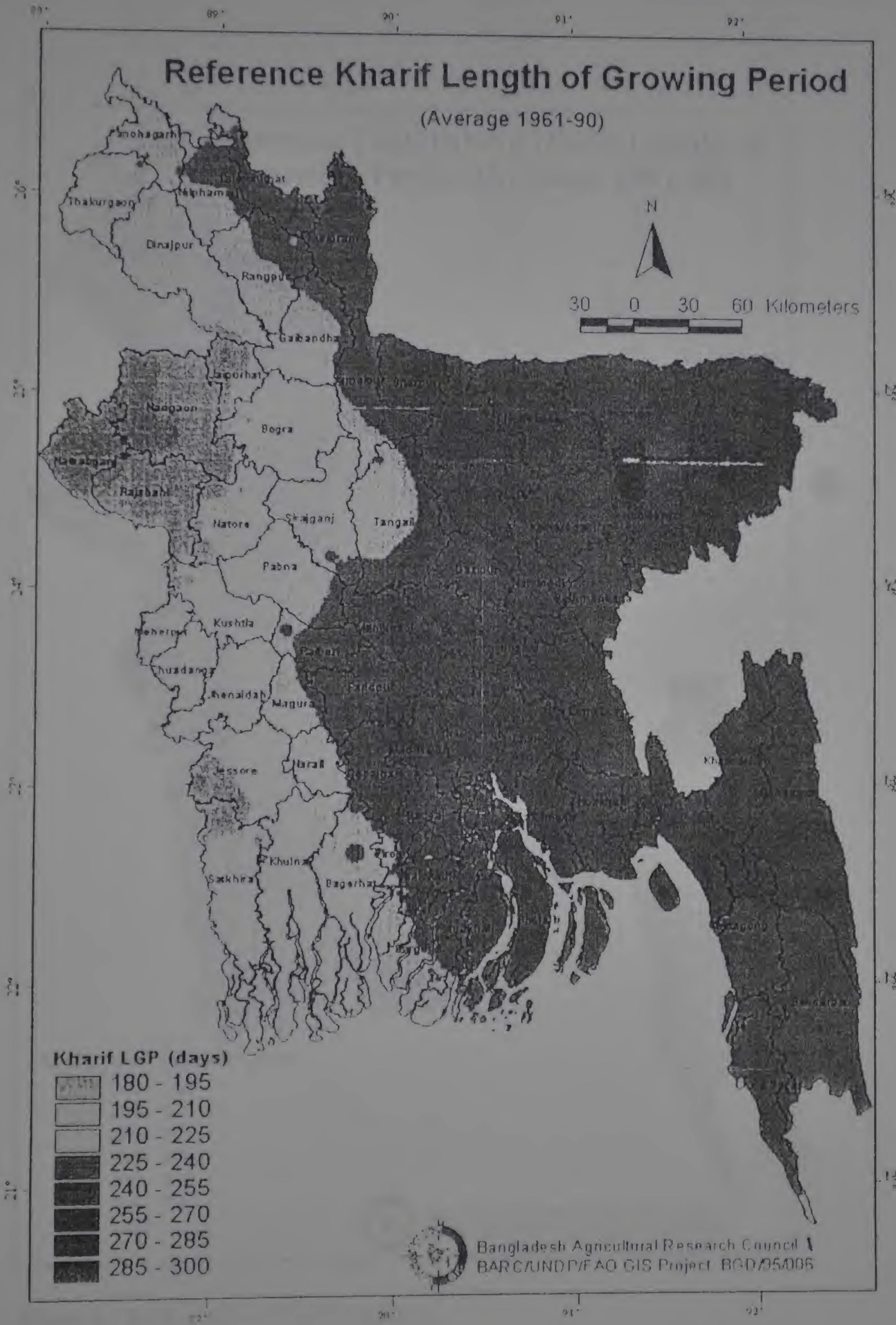

Figure 3 : Kharif LGP Theme

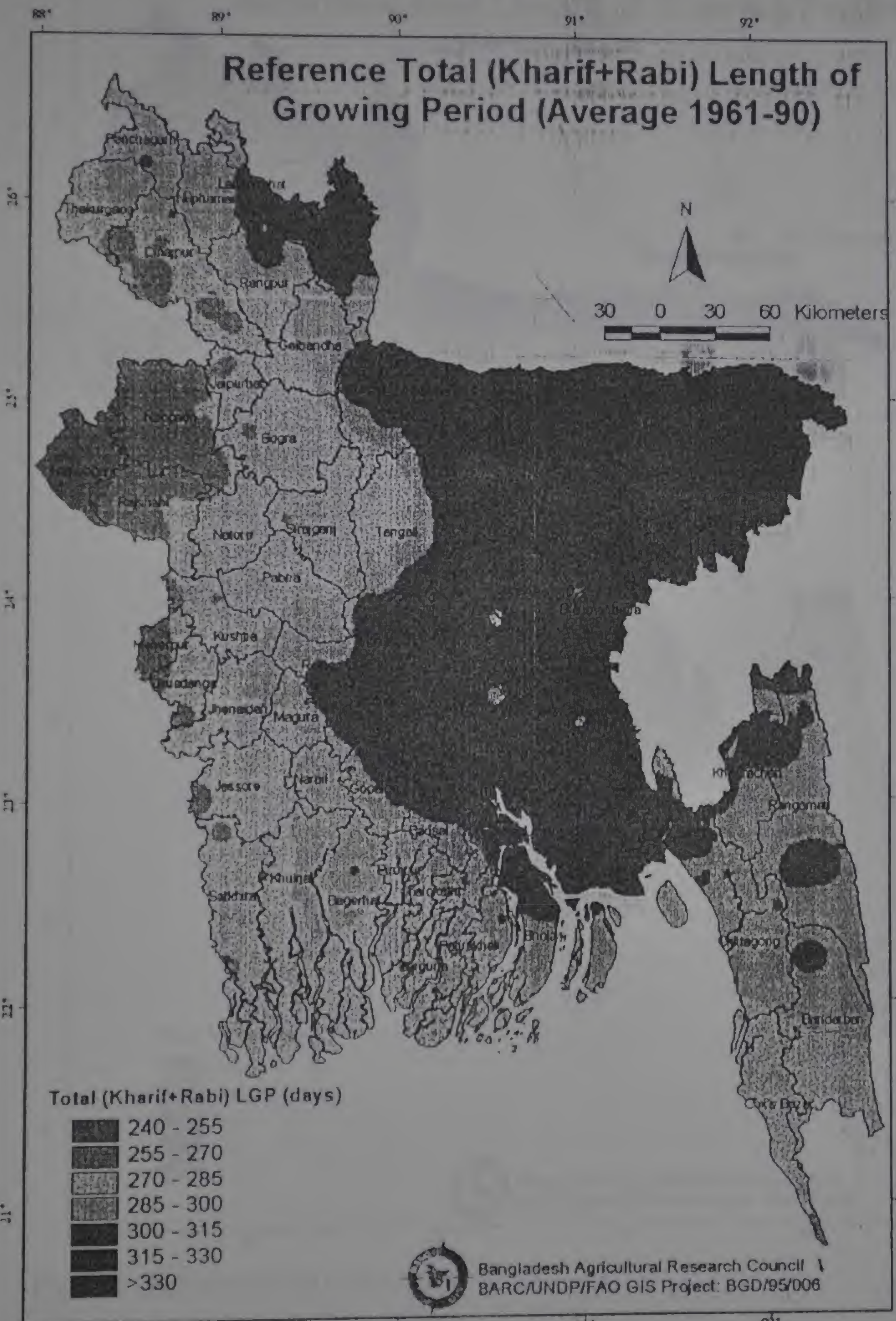

Figure 4 : Total Length of Growing period

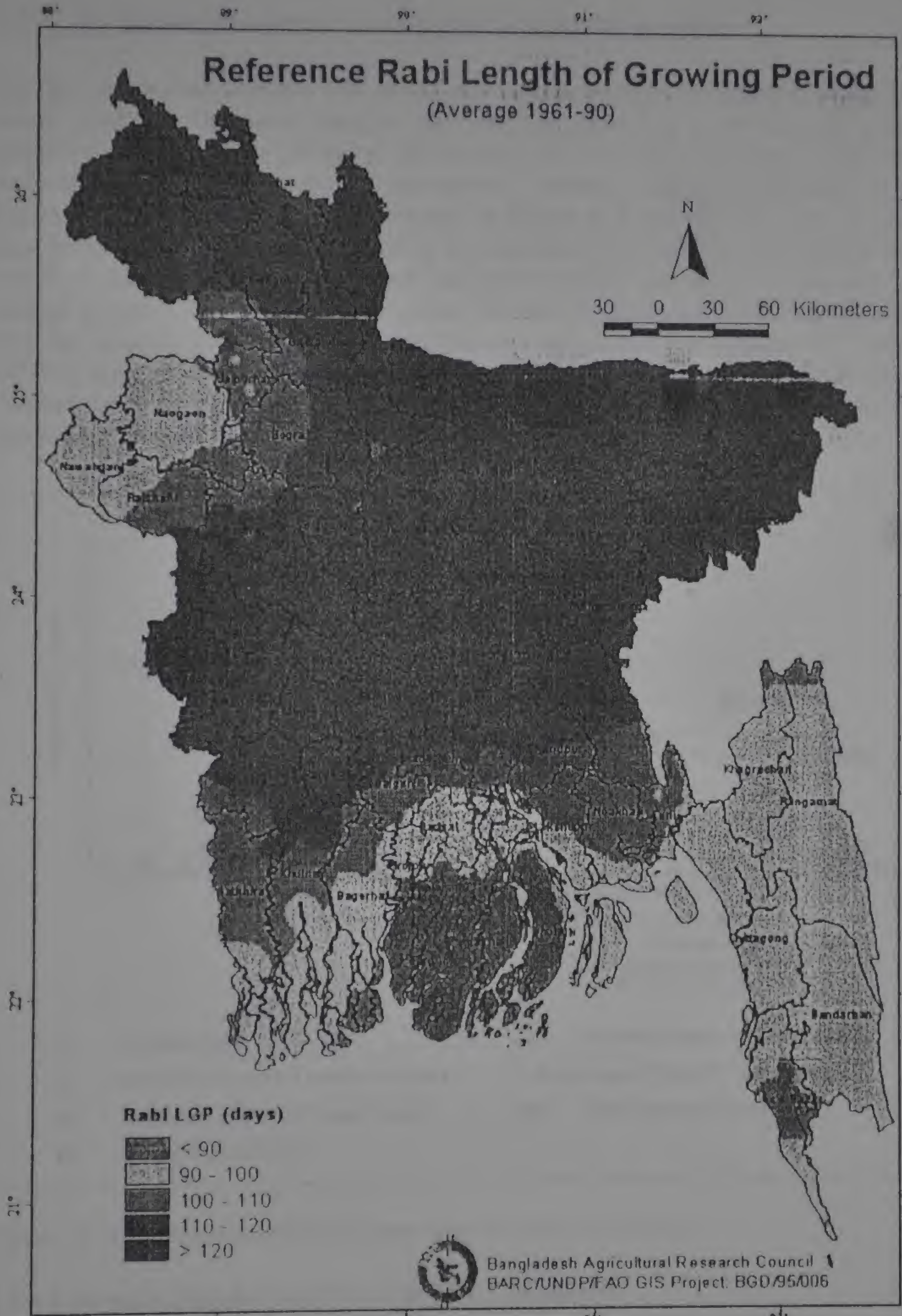

Figure 5 : Reference Rabi LGP (days)

5.3.4 Dry Sub-humid decades and Moist Sub-humid decades

The dry sub-humid decades and moist sub-humid decades is different cropping seasons factors determine the stress situation that could be prevailing in the corresponding session concerned. Decadal calculation is the modest interval that has been considered for the analysis in the current study. An atmospheric moisture balance is assumed as shown in Figure-6 to calculate the above parameters. In Figure 6, P and PET vs. time are plotted. The days having P < 0.5PET is considered as dry Sub-humid period. The days having P > 0.5PET and P <= PET is considered as moist sub-humid period and the no of decades having no rainfall is called dry decades. The number of days having P > PET is called humid period. Average monthly PET (calculated using Penman-Montieth formulas) has been calculated by APT4.0 using daily time series climatic data of 1961-1990. Decadal PET is calculated the division by 3 of the monthly PET value. The P value has been considered here as the dependable rainfall that is the rainfall at 80% probability.

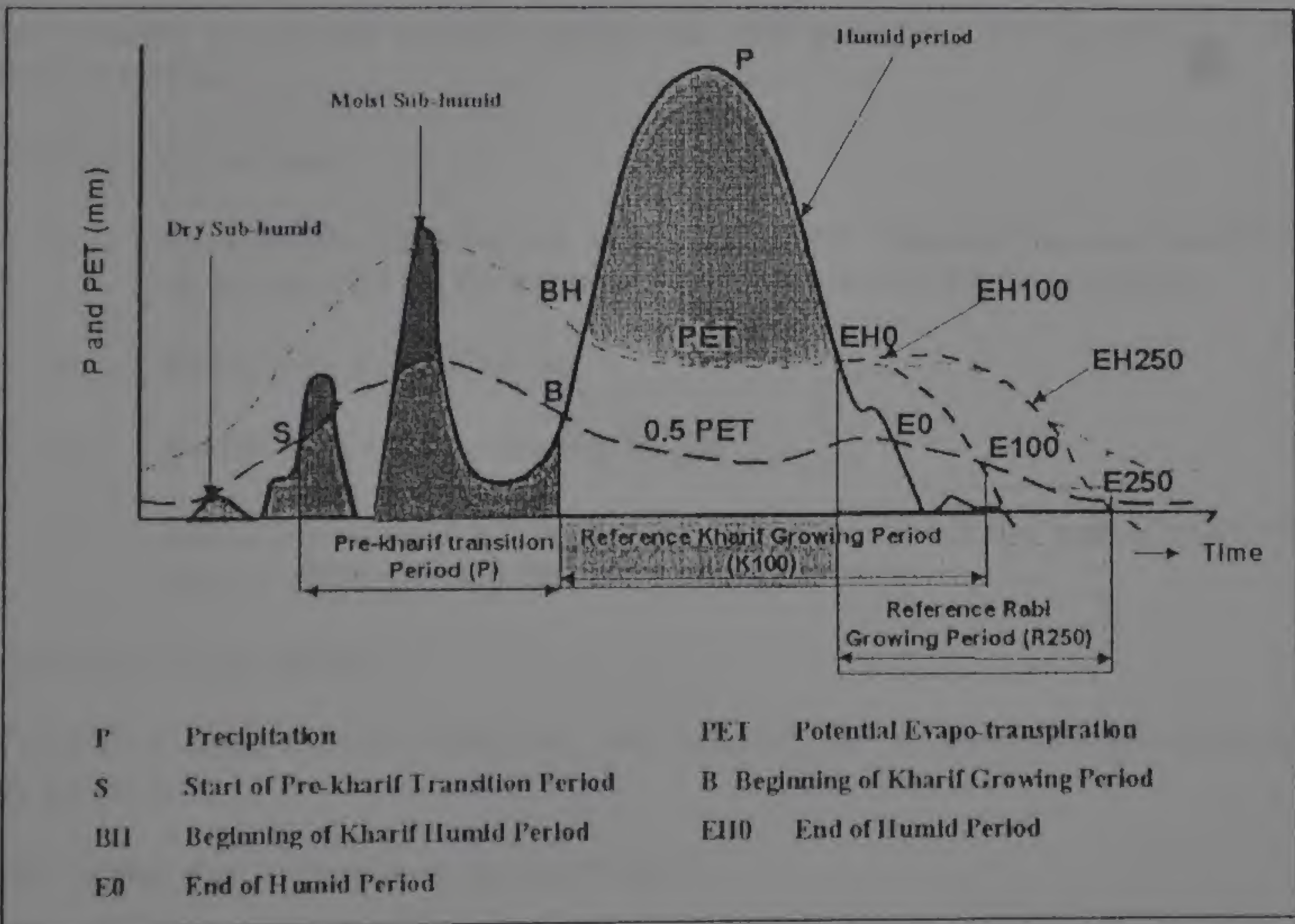

Figure -6: Conceptual diagram of atmospheric moisture balance

5.3.4.1 Decadal Rainfall and Decadal PET Calculation

From the decadal rainfall data of different years of record, rainfall at any frequency of occurrence for as many as stations are desired is expected has been calculated using a FORTRAN program (Appendix A). Following are the necessary steps to calculate rainfall frequency file and a decadal ET value from the decadal rainfall and monthly PET data.

Prepare inputs for the program: Average monthly PET file, a listing of rainfall stations files and decadal rainfall files (as per APT4.0 decade file format) are the inputs.
Run the rfpdec.exe, give the input files, first ET file and secondly the file having the rainfall file listing

Note: Input files should be located at same directory location, from where the program is being executed

Give Output decadal PET file and output Rainfall file name and then it asks the percentage of probability is expected. Finally it gives expected results.

Two output files are calculated one is the decadal ET and another is decadal Rainfall at the required probability. One extra column is added in the rainfall file, which is number of year records. If number of years record is >= 30 years, the probability values are significant.

An example of decadal PET and rainfall at desired probability calculation:

For example to calculate decadal rainfall with 75% probability and decadal PET of the BWDB stations

Following are the inputs:

i) The BWDB rainfall data file is stored in **NT2\\C:\Hasan\Clim-Analysis\BWDB** all the .dec files are the historical rainfall data in APT4.0 Decadal format

ii) **Rnlist** is the Rainfall file list

iii) **BWDB-ET.prn** is the monthly ET file

iv) Enter output decadal ET "wdbet.dec" and output rainfall file "wdbrn75.dec" and type 75, when it asks the probability of occurrences.

Following are the outputs:

Two files as inputted earlier "wdbet.dec" and "wdbrn75.dec" are cretaed during execution of the program

The "**wdbet.dec**" output file is as shown below :

```
1  25.9  25.9  25.9  32.6  32.6  ...................... Upto 36 columns
2  ..............................
3  ....................
```

and the "**wdbrn75.dec**" output file is as shown below:

```
1  33  .0  .0  .0  .0  .0  .0  ...................... Upto 36 colum
2  15  .0  .0  .0  .0  .0  .0  ...................... Upto 36 colum
3 ......
4 ...
```

Similar calculated is to be followed for the BMD station files are stored in NT2\\C:\Hasan\Clim-Analysis\BMD directory

5.3.4.2 Calculation of Decadal Water balance

The files created above were used to calculate the decadal atmospheric water balance data. A FORTRAN program was written to calculate P-0.5 PET, where P = Dependable rainfall and PET is the decal PET. Listing of the program is given in Appendix-B. It takes the output files generated as discussed in section 4.2.2.1 as inputs and creates the a output file containing four rows of information for each stations. First row gives the rainfall (at the requested probability), second row gives the decadal PET values, third row gives the 0.5PET values and the fourth row gives the P-0.5PET values.

Output listing is as shown in below :

```
1 1     .0    .0     0    .0    .0    .0    .0    .0  10.0 ..P Values
1 2  25.9  25.9  25.9  32.6  32.6  32.6  46.4  46.4  46.4 .. PET values
1 3  12.9  12.9  12.9  16.3  16.3  16.3  23.2  23.2 ........ 0.5PET values
1 4 -12.9  12.9 -12.9 -16.3 -16.3 -16.3 -23.2 -23.2 ..... P-0.5PET values
```

This decadal water balance information can be mapped using GIS and also can be presented in graphs. In graphs time series (year round) water balance is shown (Figure-7). In map form spatial variation of water balance condition at a particular time (e.g. at any decade) can be presented.. Both are useful in assessing the atmospheric water balance condition at a particular location for the specified period.

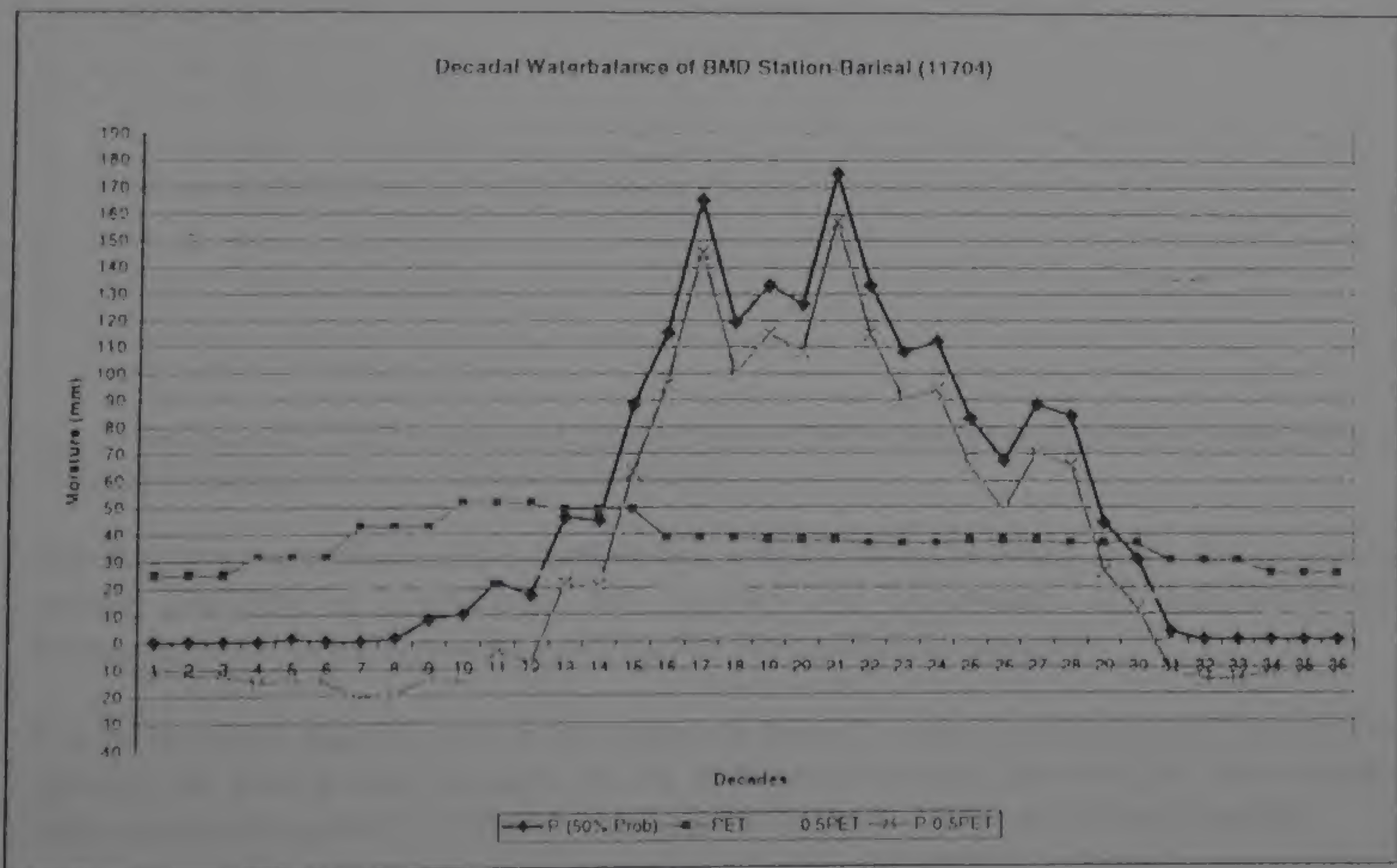

Figure 7: An example of water balance plot of the Barisal Station at 50% rainfall probability

5.3.4.3 Calculation of percentage dry decades and percentage dry sub-humid decades
Using the output file of the decadal water balance (section 4.2.2.2), frequency of (number) dry decades, dry sub-humid decades, moist sub-humid decades and humid decades are calculated. A program called droughtpar.exe is written for this purpose. The source code is given in Appendix-C. The input, output files and the exe file resides at NT2\\C:\Hasan\Clim-Analysis\Droughtpar\debug directory. During execution of the program, the user is asked to provide start decades and end decades for calculation in addition to the output file containing the number of decades having dry sub-humid, dry decades and most sub-humid and humid decades. Moist sub-humid and humid decades are not used in the drought severity calculation.

An Example of calculation procedure:

Say for example drought parameters for the BWDB stations for the pre-kharif transition is to be calculated. At first it is to be ensured that the program file and the input file reside at same directory location. In this case the files resides at NT2\\C:\Hasan\Clim-Analysis\Droughtpar\debug directory. Now run **droughtpar.exe** from the DOS prompt or from the file explorer window. During execution the program asks for the name of the input file and the output file. Enter input file as BWDBWB80 (where decadal water balance information are found, as discussed in 4.2.2.2) and output file as PK0715.txt, enter 7 as start decades (start of March) and 15 as the end decades (End of May). The output file consists of five columns as shown below:

```
1  0  1  8  5
2  0  3  6  5
3  0  0  9  6
4  0  1  8  4
5  1  2  6  4
6  0  2  7  5
7  0  0  9  5
9  0  3  6  4
10  0  2  7  4
......................
......................
```

Col-1 : Station code ; Col-2 - Number of Humid decades, Col-3 : Number of Moist Sub-Humid, Col-4 :Number of Dry sub-humid and Col-5 - Number of dry decades.

The first column (station ID) is used to link with the corresponding shape file or coverage for surface creation of percentage dry decades and percentage dry sub-humid decades. Percentages are calculated after opening this file in EXCEL program.

It is to be noted that the sum of the values of humid, moist sub-humid and dry sub humid is equal to the total period, because the dry sub-humid decades also includes dry decades. The fifth column (dry period) is the total no rainfall decades within the analysis period.

Using the above data file and the station shape file, percentage dry decade and percentage dry sub-humid decade surface for both pre-kharif and kharif seasons were prepared as shown in Figure 8, 9, 10 and 11. Percentage of dry decades and percentage of dry sub-humid decades also calculated for the Rabi period but since most of the time of this season (i.e. October - February) is normally no rainfall, this factors carries less importance than the rabi season

irrigation. The rabi season irrigation percentage based on the NMIC (National minor irrigation census) data of 1996/97 season is shown in the map (Figure 12). This was also considered during the Rabi season drought estimation.

Percentage of dry sub-humid decades and dry decades was considered to quantify drought severity for the season concerned. Percentage cut off points of the dry sub-humid and dry decades classes for quantifying the drought severity is presented in Table 12.

Table 12 : Percentage cut off for the drought classification

Drought weight	Drought prone areas	Percentage cutoff of the dry factors	
		Dry sub-humid period	Dry decades
1	Very severe drought prone areas	>80	>80
2	Severe drought prone areas	65-80	65-80
3	Moderate drought prone areas	45-65	45-65
4	Slight drought areas	30-45	30-45
5	No drought prone areas	<30	<30

Using the above cutoff points six weight surfaces (two for each season, one for dry sub-humid and one for dry decades), showing drought prone zone due to the above factors for each seasons was calculated.

In a concise form the weight value for all the climatic parameters calculated using the above methodology is given in Table 13.

Table 13: Assignment of weight to individual climatic factors

Factor	Values of different factors				
Weight	1	2	3	4	5
Pre-Kharif Transition period	>60 days	50-60 days	40-50 days	30-40 days	< 30 days
Kharif LGP	< 200 days	200-220 days	220-240 days	240-260 days	> 260 days
Rabi LGP	<90 days	90-100 days	100-110 days	110-120 days	> 120 days
Total LGP	240-255 days	255-270 days	270-285 days	285-300 days	> 300 days
Pre-Kharif Dry Decades	>71 %	63-71 %	46-63%	29-46%	<40%
Pre-Kharif Dry Sub-humid	>90%	80-90%	60-80%	40-60%	<40%
Kharif Dry Decades	>18%	15-18%	12-15%	9-12%	<9%
Kharif Dry Sub-humid	22-30%	19-22%	15-19%	12-15%	<12%

Weights implies (1-Very High, 2-High, 3-Moderate, 4-Slight 5-None) prone to drought for the specific factor

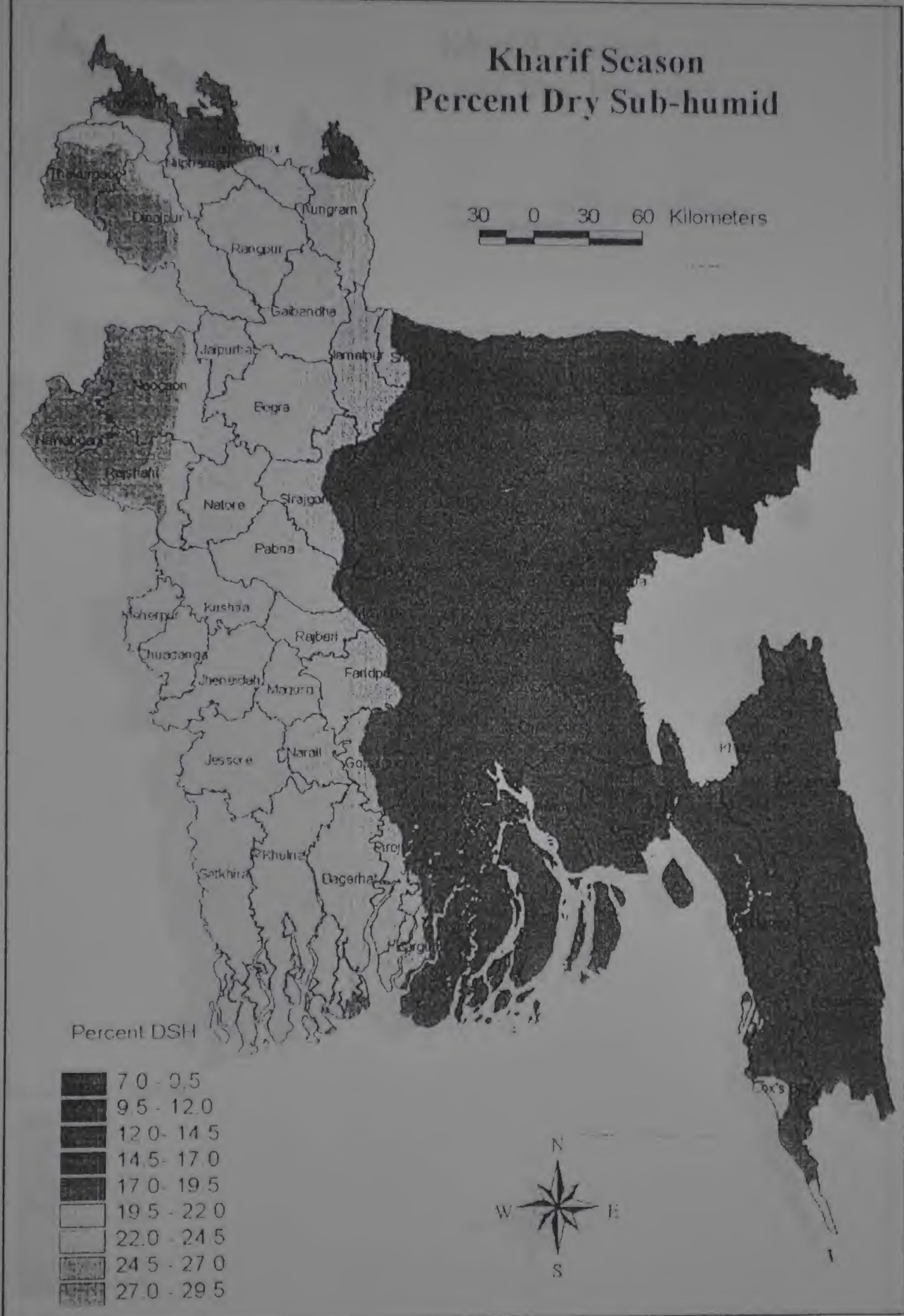

Figure 8: Surface of the Kharif season percent dry sub-humid decades

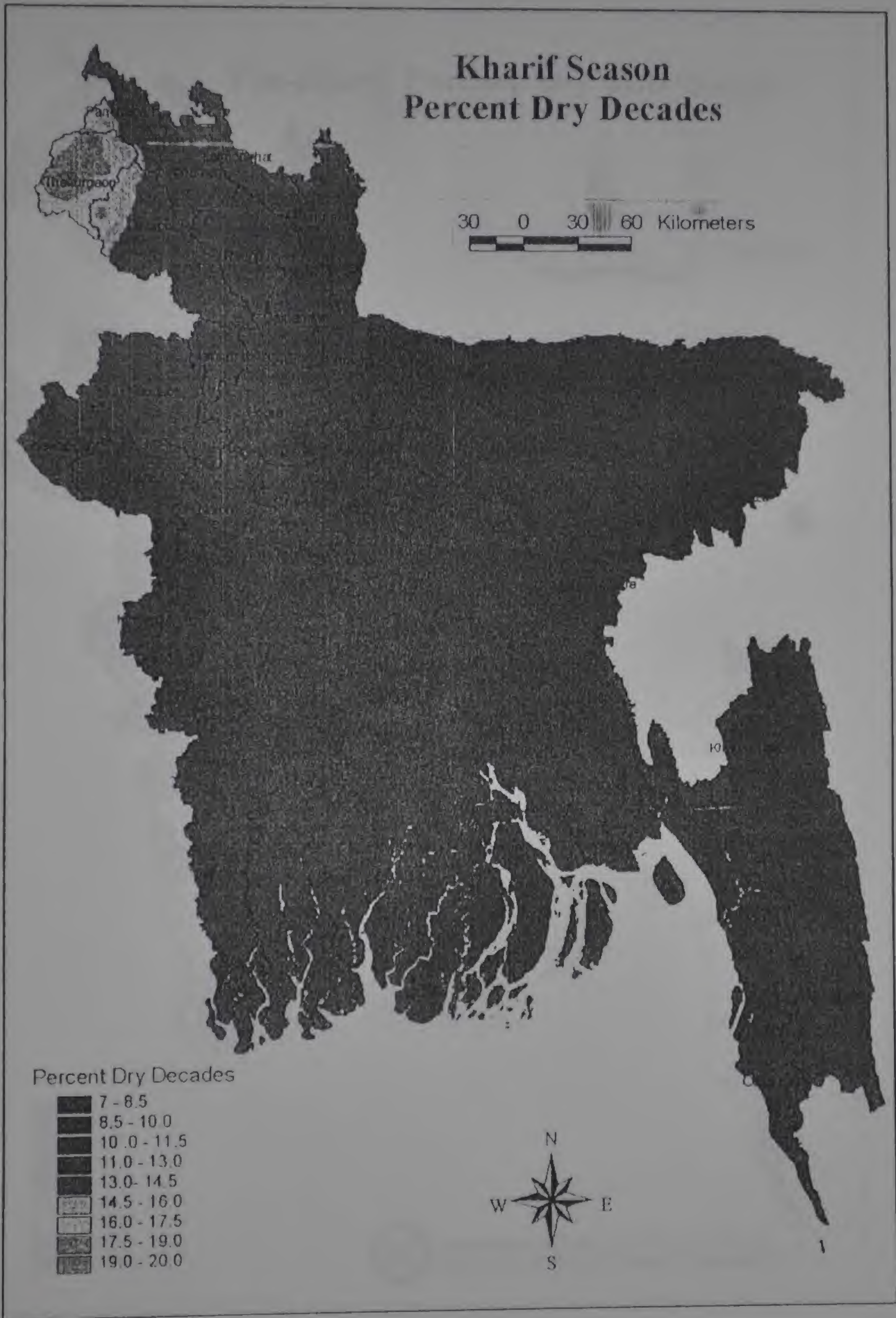

Figure 9 : Kharif season percent dry decades surface

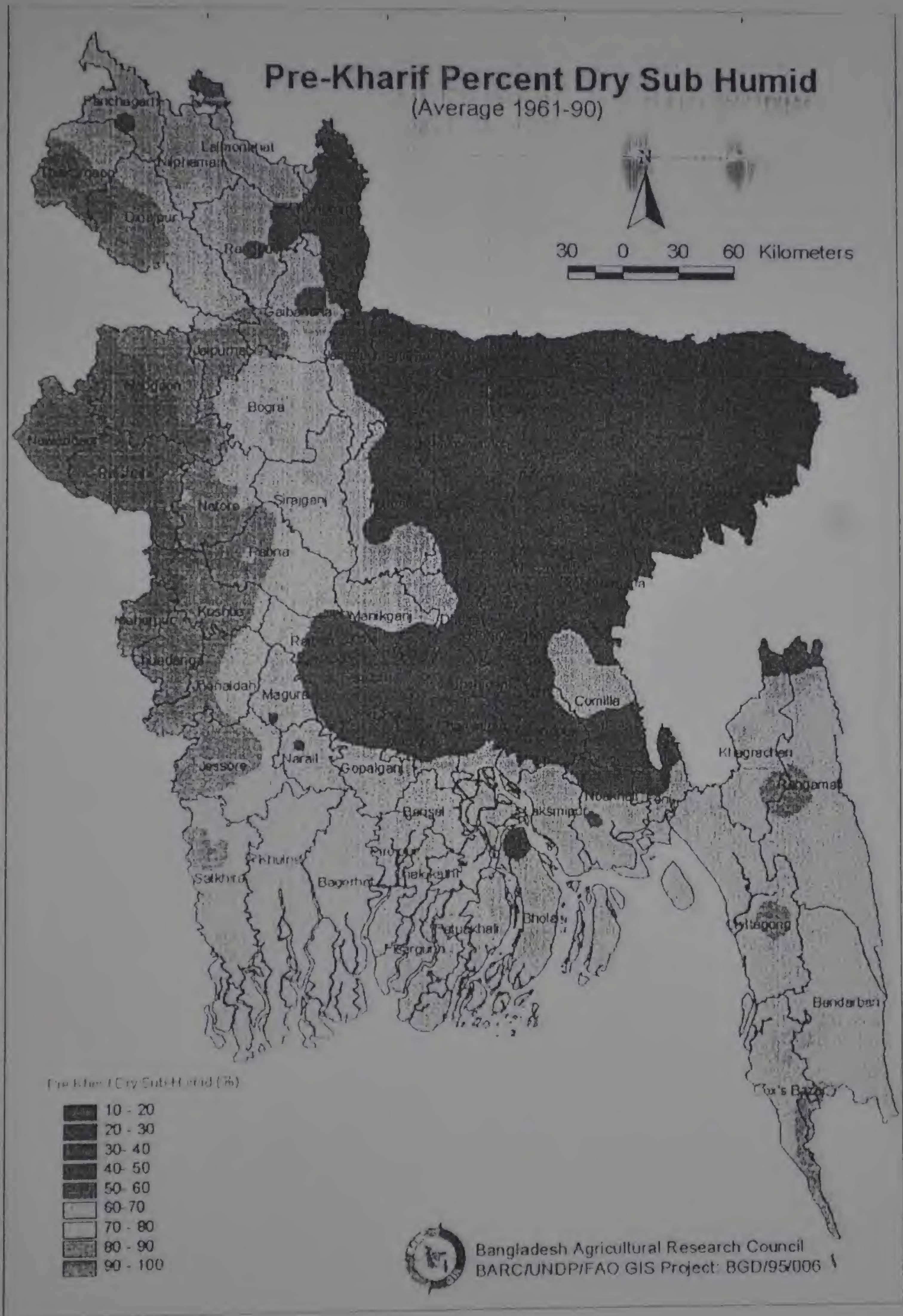

Figure 10 : Pre-Kharif season percent dry sub-humid decades

Figure 11 : Pre-Kharif percentage dry decades surface

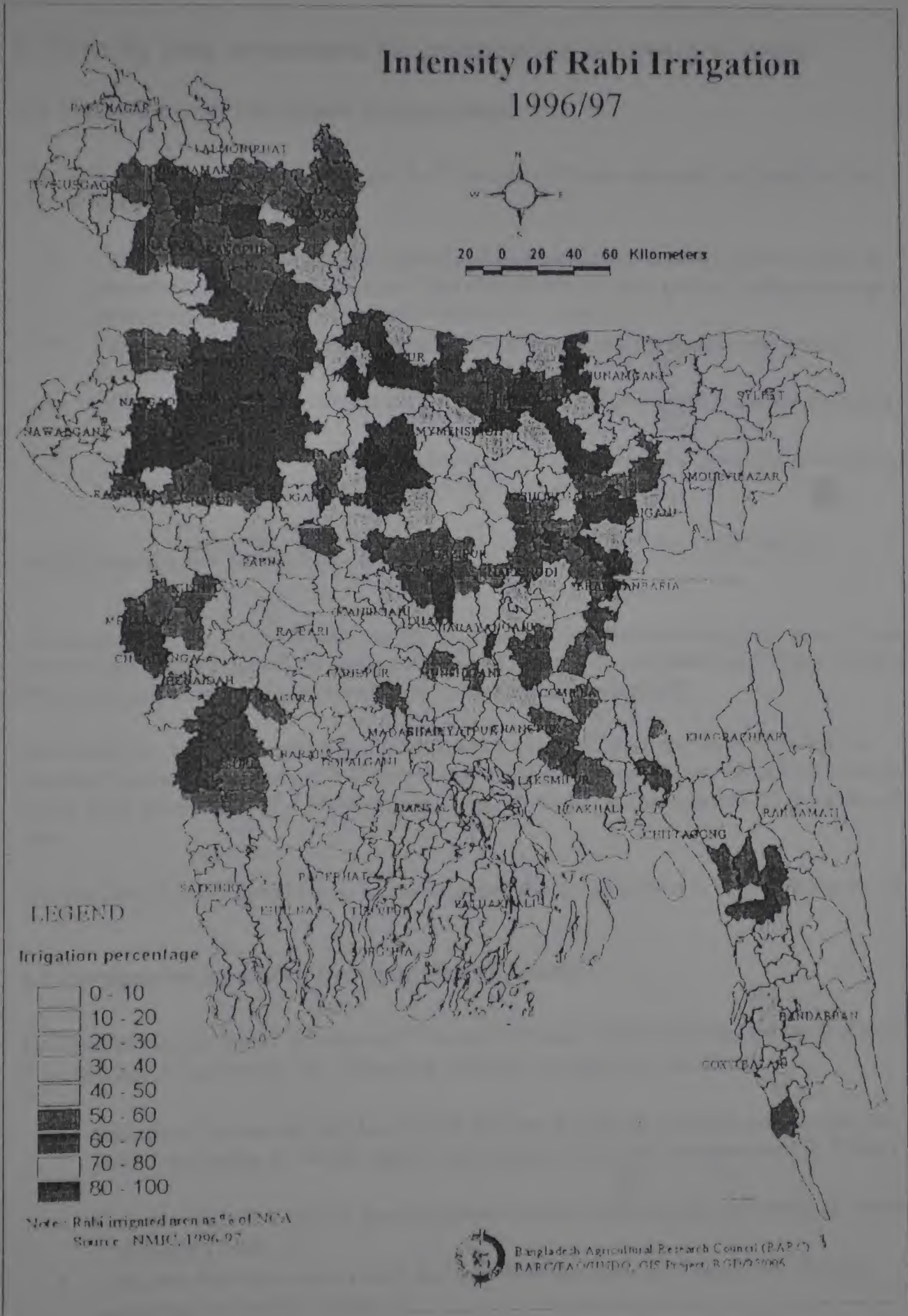

Figure 12 : Intensity of Rabi Irrigation (% of NCA) of 1996/97 Rabi season

6. Step by step procedure for preparation of drought maps.

6.1 Preparation of Pre-Kharif Drought Map

The time period for pre-kharif drought is 2nd decade of March through 1st decade of June (Week 8 to Week 16) period.

- Calculate percentage dry sub-humid and percentage dry decades surface using the procedure mentioned in section 4 and classify the surface grid according to weight signifying severity of drought as mentioned in Table 13.
- Calculate Soil-association wise moisture holding capacity surface and classify according to drought severity weights (Table .
- Calculate Pre-kharif growing period surface and assign weight to different classes according to Table 13.
- Calculate overall pre-kharif drought index, by combining the above mentioned four weight grid surfaces using the following formula

$$PKHDrIndex = \frac{(MHCWt * 40) + (KHLGPWt * 25) + (DSHWt * 20) + (DDWt * 15)}{10}$$

Minimum value for the pre-kharif overall index would be 10 considering very severe drought situation prevailed from all the factors concerned (weight-1) and maximum value would be 50 considering very good moisture situation for the crop (weight-5).

An overall pre-kharif drought index is obtained starting values from 16 to 50, where a severity is assigned in terms of 5 different classes of the above indices. 16-20-Very severe, 21-26 Very severe class, 26-31-Moderate Class, 32-40 Slight class and 41-50 is no drought class.

The final Pre-Kharif drought map found from the above calculation is shown in Figure 13.

6.2 Preparation of Kharif Drought Map (T.Aman)

The time period for Kharif drought is 2nd decade of June- end of October for the T.Aman Crop (decade 17 to decade 30). Following different surfaces are calculated:

- Calculate Percent dry sub-humid and Percent dry decades surface and classify the values according to weight signifying severity of drought as mentioned in Table 13.
- Calculate Kharif length of growing period surface and classify according to severity of drought (Table 13)
- Calculate Soil-association wise moisture holding capacity surface and classify according to severity (Table 9)
- Combine the above mentioned four surfaces to create a cumulative drought index using following formula.

$$PKHDrIndex = \frac{(MHCWt * 40) + (KHLGPWt * 25) + (DSHWt * 20) + (DDWt * 15)}{10}$$

Reclassify the cumulative grid according to the level of severity (10-16, Very severe, 17-21 Severe, 22-27 Moderate, 27-34 Slight and >34 is nil or no drought.)

In this map some not T.Aman areas were excluded from the mapping considering the fact that this map is prepared to show drought severity to T.Aman crop only. Not T.Aman areas are those areas having landtype Lowland to very low land. Hilly regions are also excluded from the mapping. Therefore a non-T.Aman area grid is obtained first and after doing some grid operation (mainly the setnull and con request) the final T.Aman drought map is obtained as shown in Figure 14.

6.3 Preparation of Rabi Drought Map

The time period for Kharif drought is 1st decade November-1st decade of March for the major rabi crops (decade 31 to decade 7). Following different surfaces are calculated:

- Calculate Percent dry sub-humid and Percent dry decades surface and classify the values according to weight signifying severity of drought as mentioned in Table 13..
- Calculate Rabi length of growing period surface and classify according to severity of drought (Table 13)
- Calculate Soil-association wise moisture holding capacity surface and classify according to severity (Table 9)
- Combine the above mentioned four surfaces to create a cumulative drought index using following formula.

$$PKHDrIndex = \frac{(MHCWt * 40) + (KHLGPWt * 25) + (DSHWt * 20) + (DDWt * 15)}{10}$$

Reclassify the cumulative grid according to the level of severity (10-16, Very severe, 17-21 Severe, 22-27 Moderate, 27-34 Slight and >34 is nil or no drought.

Finally the drought prone area map for the Rabi season is obtained as shown in Figure 15.

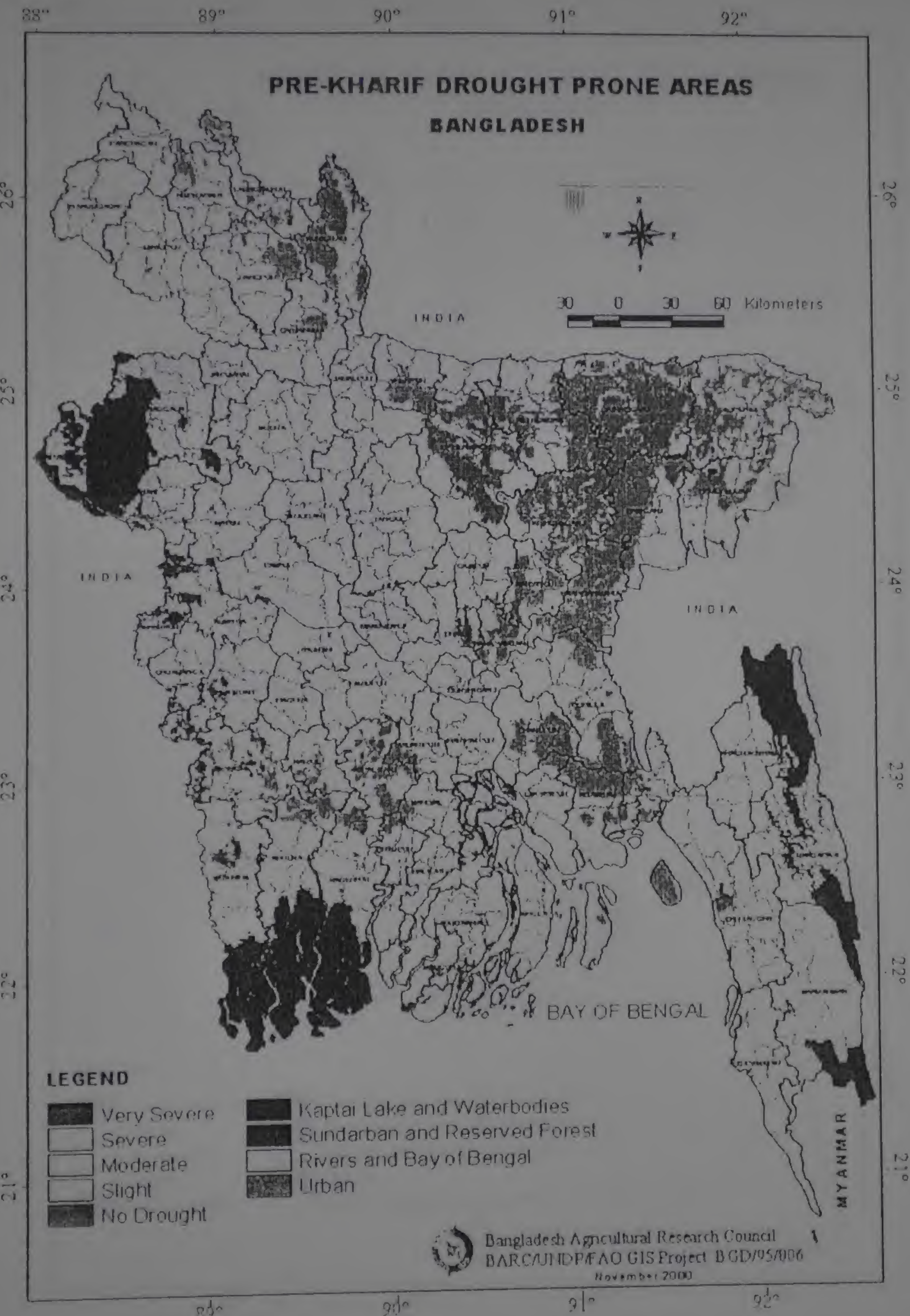

Figure 13 : Pre-Kharif drought prone area map

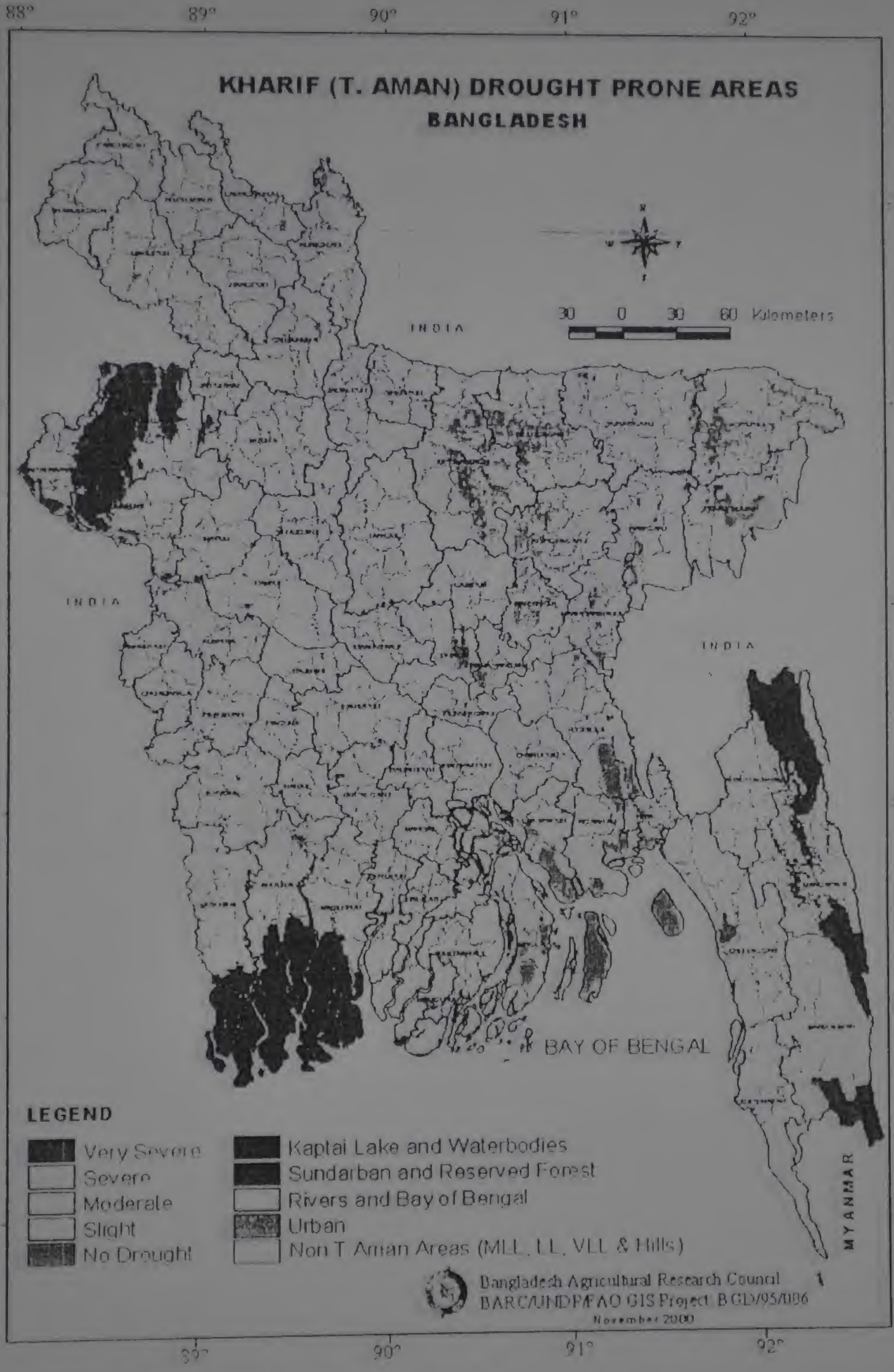

Figure 14 : Kharif - II (T.Aman) drought prone area map

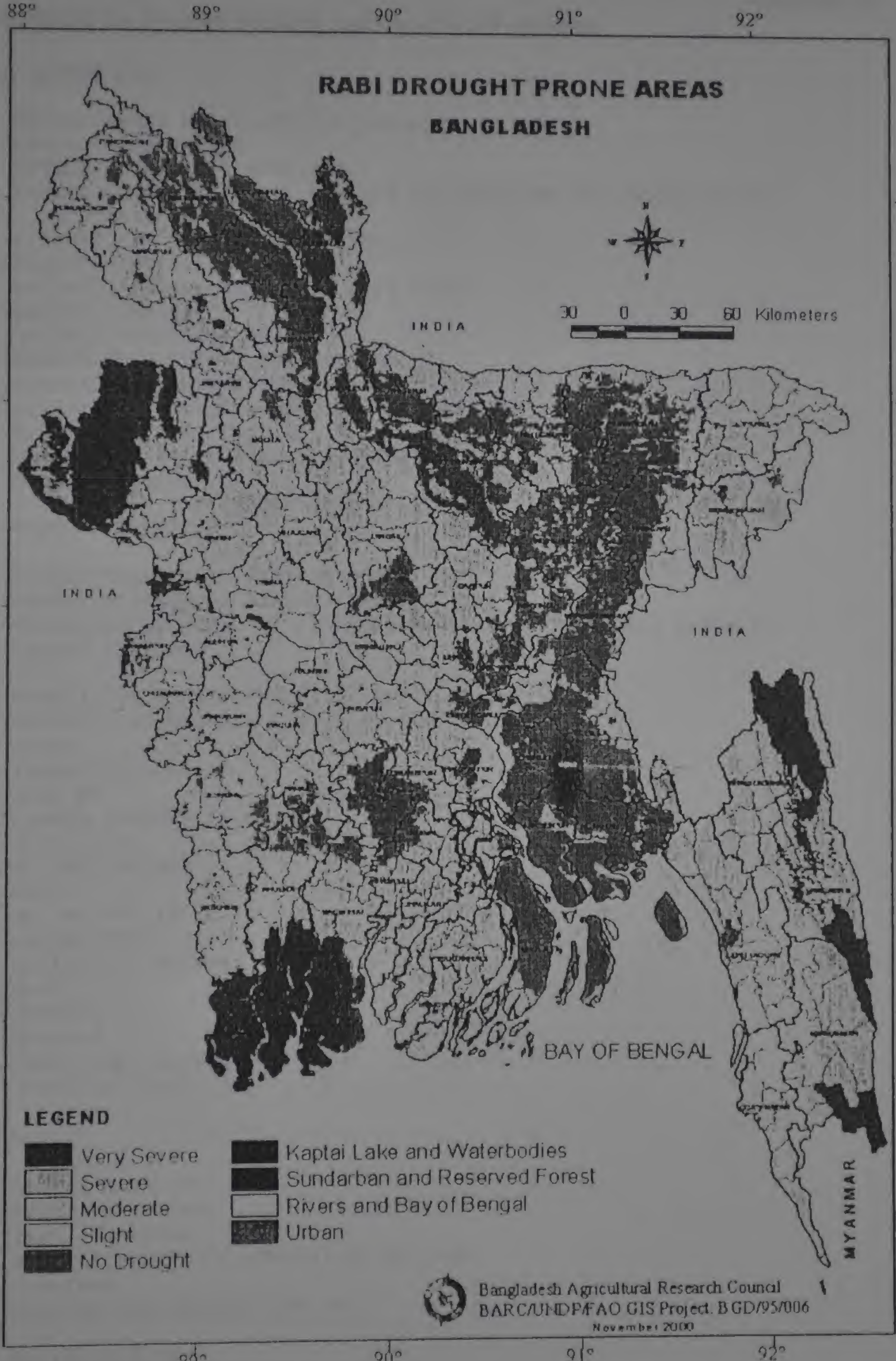

Figure 15 : Rabi drought prone areas

Appendix A

Program listing for Decadal Rainfall and Decadal ET creation

```
PROGRAM RNPROB.FOR
C
      Character*11 ETfile,RNlist,Dummy,ETout,RNout
      Character*9 Rnfile
      INTEGER Dec(12,3),NSTP(300)
      DIMENSION DPET(300,36),PET(300,12),DRAIN(40,36),PRAIN(40,36),
     + DVAL(36)
      write(*,*) 'Enter the ET-File :'
      Read(*,*)ETfile
      write(*,*)'Enter Rainfall file List'
      Read(*,*)RNlist
      write(*,*)ETfile, RNlist
      open(3,FILE=ETfile,STATUS='OLD')
      open(4,FILE=RNlist,STATUS='OLD')
      write(*,*) 'Enter output decadal ET-File :'
      Read(*,*) ETout
      write(*,*)'Enter output decadal Rainfall file :'
      Read(*,*)RNout
            write(*,*)'Enter probability (%) of decadal Rainfall :'
      Read(*,*) RNProb

      Open(6,FILE=RNout,STATUS='NEW')
      open(7,FILE=ETout,STATUS='NEW')
C     Calculate Decadal PET from the Monthly PET and then write it
      read(3,*) Dummy
      I=1
  90  Read(3,120,END=130)NSTP(I),(PET(I,J),J=1,12)
      write(*,120)NSTP(I),(PET(I,J),J=1,12)
      I=I+1
 120  format(I5,12F6.1)
      Goto 90
C     Create Decadal file
 130  NST = I-1
      DO 160 I=1,NST
      NR=0
      DO 160 J=1,12
      DECPET=PET(I,J)/3.0
      Write(*,*) DECPET
C     NC=0
C 111 NR=NR+1
C     NC=NC+1
CC    DPET(I,NR)=DECPET
C     IF(NC.LT.3)GOto 111

      NC=J*3
       NNC=NC-2
      DO 140 N=NNC,NC
      DPET(I,N)=DECPET
      140   continue
c     Write(*,*)NSTP(I),(DPET(I,M),M=1,36)
160   continue
C     Writing the decadal PET data

      DO 190 I=1,NST

      Write(7,180)NSTP(I),(DPET(I,J),J=1,36)
```

```
 180    format(I5,36F6.1)
 190    continue
        Close(7)

C ******** End of the Decadal ET Calculation and writing

C ************ Start of Rainfall Data reading, sorting and calculating prob
C       NPST=0
  5     read(4,10,END=1000)Rnfile
 10     Format(A9)
C       NPST=NPST+1
        open(5,FILE=Rnfile,STATUS='OLD')

C       Initialize the Sums
        DO 50 I=1,36
        DVAL(I)=0
        50    CONTINUE

        NYR=0
100     NYR=NYR+1
        DO 200 I=1,12
        READ(5,20,END=999) NST,(Dec(I,J),J=1,3)
20      Format(4X,I5,8X,3I7)

200     CONTINUE
        NR=0
        DO 500 I=1,12
         Do 500 J=1,3
         NR=NR+1
           DRAIN(NYR,NR)=Dec(I,J)    !DRAIN(300,36)-> Decadal Rain
 500    CONTINUE

        GOTO 100
999     NYR = NYR -1
C   *** End of reading one station data where NYR = No of years, NR-
Decadess
C       Sorting the Data for Probability Calculation PRAIN(NYR,NR)-
>DRAIN(NR)
         DO 350 NR = 1,36

         DO 330 I = 1,NYR
          Max=DRAIN(I,NR)
          Maxpos = I

         K=I+1
         DO 320 J=K,NYR
          IF(DRAIN(J,NR).GE.Max) THEN
           Max = DRAIN(J,NR)
           Maxpos = J
          ELSE
           GOTO 300
          END IF
300     CONTINUE
320     CONTINUE
              PRAIN(I,NR)=Max     !PRAIN-> is the max of the serieses
C       SWAP the data with the Initial position & the Max position
        temp=DRAIN(I,NR)
        DRAIN(Maxpos,NR)=temp
330     CONTINUE
```

```
C       Calculate rank with the given Probability value and extract the data
        RANK=RNPROB*(NYR-1)/100
        IRANK=INT(RANK)
        DVAL(NR)=PRAIN(IRANK,NR)

350     CONTINUE
        WRITE(6,610)NST,NYR,(DVAL(I),I=1,36)
 610    Format(I5,1X,I3, 36F7.1)
        Close(5)
        GOTO 5

1000    Close(4)
        Close(6)
        Stop
        End
```

Program listing for Decadal Water balance calculation

```
Program PETDATA.FOR
        Character*11 ETBMD,RNBMD,ETBWDB,RBWDB,RNOUT
        Character*9 BMDDEC,BWDBDEC
        INTEGER NSTP(300),NSTR(300)
        REAL PET(300,36), RAIN(300,36), RNMPET(300,36),HPET(300,36)
        write(*,*) 'Enter the decadal ET-File :'
        Read(*,*)ETBMD
        write(*,*)'Enter decadal Rainfall file :'
        Read(*,*)RNBMD
        write(*,*)'Enter output file file :'
        Read(*,*)RNOUT
c       write(*,*) 'Enter the BWDB decadal ET-File :'
c       Read(*,*)ETBWDB
c       write(*,*)'Enter BWDB Rainfall file :'
c       Read(*,*)RBWDB
        open(3,FILE=ETBMD,STATUS='OLD')
        open(4,FILE=RNBMD,STATUS='OLD')
c       open(5,FILE=ETBWDB,STATUS='OLD')
c       open(6,FILE=RBWDB,STATUS='OLD')
        open(7,FILE=RNOUT,STATUS='NEW')
c        Read the BMD file first in the memory variables
        NSTPET=0
        DO 20 I=1,300
        read (3,10,END=30)NSTP(I),(PET(I,J),J=1,36)
 10     Format(I5,36F6.1)
 20     Continue
 30     NSTPET=I-1
        NSTRN=0
        DO 50 I=1,300
        read (4,40,END=60)NSTR(I),(RAIN(I,J),J=1,36)
 40     Format(I5,4X,36F7.1)
 50     Continue
 60     NSTRN=I-1
        Print*, 'No of BMD ET Stations:',NSTPET
        Print*, 'No of BMD RN Stations:',NSTR
        DO 100 I=1,NSTPET
        DO 110 J=1,NSTRN
        IF(NSTP(I).NE.NSTR(J))goto 110
        write(7,120) NSTR(J), (RAIN(J,K),K=1,36)
        write(7,130) NSTP(I), (PET(J,K),K=1,36)
        do 90 K=1,36
         RNMPET(I,K)=RAIN(J,K)-0.5*PET(I,K)
        HPET(I,K)=0.5*PET(I,K)
 90     continue
        write(7,150) NSTP(I), (HPET(I,K),K=1,36)
        write(7,140) NSTP(I), (RNMPET(I,K),K=1,36)

        goto 100
 110    continue
 100    continue
 120    format(I5,' 1',36F6.1)
 130    format(I5,' 2',36F6.1)
 150    format(I5,' 3',36F6.1)
 140    format(I5,' 4',36F6.1)
        STOP
        END
```

Program listing for Drought parameter calculation

```
c      Program DROUGHTPAR.FOR
c      Takes input from the WB80.Out file, there are four rows data exists
for all the stations
         Character*10 InFile,OutFile,Dummy
       REAL P(36), PET(36),HPET(36)
       Write(*,*) 'Enter the Input File Name:'
         Read(*,11)InFile
11       FORMAT(A10)
         Write(*,*)'Enter Analysis Output File Name :'
         Read(*,11)OutFile
       Open(3,FILE=InFile,STATUS='OLD')
       Open(4,FILE=OutFile,STATUS='New')
         Open(5,FILE='PRN')
         Write(5,*)'Station   Humid    MSH       DSH     Dry Days'
       Write(*,*)'Analysis Basis are following (No of Days):'
       Write(*,*)'Humid             -> P>PET'
       Write(*,*)'Moist Sub-Humid -> P>0.5PET'
         Write(*,*)'Dry Sub-Humid   -> P<=0.5PET'
       Write(*,*)'Dry Days          -> P=0'
       Write(*,*)'=========================='
         Write(*,*)'Mon:Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec'
         Write(*,*)'Dec:1 3 4 6 7 9 10- 13- 16- 19- 22- 25- 28- 31- 34-'
         Write(*,*)'=============================================='
         Write(*,*)'Pre Kharif & Rabi Drought -> March-May (Normal)'
         Write(*,*)'Kharif Drought occurs during ->Sept-Nov (Normal)'
       Write(*,*)'=============================================='

c     Enter the period (Start Decades and End Decades) for which analysis is
to be done.

       Write(*,*)'Enter Start Decades for Analysis :'
       read(*,*)NSTD
       Write(*,*) 'Enter End Decades for Analysis :'
       read(*,*)NEND
C        Write(*,*) 'Output file contains STNNo,Humid,
MoistSubHumid,DrySubHumd,Dry Decades'

       Write(*,*) 'Reading input file..'
100    Read (3,10,END=999)NSTP,(P(I),I=1,36)
       Read (3,10,END=999)NSTP,(PET(I),I=1,36)
         READ (3,10,END=999)NSTP,(HPET(I),I=1,36)
10       Format(I5,2X,36F6.1)
       READ (3,15,END=999)Dummy
15       Format(A10)
       NHUM=0
       MSH=0
       NDSH=0
       NDD=0
       DO 20 I=NSTD,NEND
       IF(P(I).GT.PET(I)) GOTO 21
       IF(P(I).EQ.0.0)NDD=NDD+1
       IF(P(I).GT.HPET(I))MSH=MSH+1
       IF(P(I).LE.HPET(I))NDSH=NDSH+1
       GOTO 20
21     NHUM=NHUM+1
20     CONTINUE
       WRITE(*,*)NSTP,NHUM,MSH,NDSH,NDD
```

```
      WRITE(5,*)NSTP,NHUM,MSH,NDSH,NDD
      WRITE(4,40)NSTP,NHUM,MSH,NDSH,NDD
40    Format(I5,4I4)
      GOTO 100
999     WRITE(*,*) '*** END OF PROCESSING  ***'
      STOP
      END
```